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# Failure patterns and implications

*During the period 1970–1974, the Building Research Advisory Service made detailed investigations of over 500 defective buildings. The reports have been analysed to discover the faults most likely to be encountered and to identify ways in which the incidence of building defects might be reduced.*

The findings of 510 investigations of building defects are analysed in Table 1 by building type, showing also the most common defects in each. It was considered that 11 per cent of the buildings had defects that could endanger life; the functional performance of 66 per cent was impaired; the remaining 23 per cent had defects of a superficial, largely aesthetic nature.

## Dampness (*see* Table 2)

Half the defects investigated were varieties of dampness; these are often related, for example, rain penetration or entrapped water in an insulating structure will increase the risk of condensation.

**Condensation** [110] Surface condensation proved to be a problem mainly of housing, particularly council housing. Significant, sometimes gross, inadequacies in heating and/or ventilation could explain every instance and it may be that council tenants are less willing or less able to provide sufficient warmth and ventilation than are the owners of private houses. The construction, however, was not necessarily blameless; it could often be argued that the thermal insulation [108] provided, though meeting the requirements in force at the time of design, was too low and the thermal mass too high for the type of occupancy involved. In the private sector, surface condensation often followed double glazing [140] and efficient draught-stripping. Unwittingly, the owners had reduced the air changes to less than the acceptable limit for the form of construction and the level of heating provided.

Interstitial condensation problems were fairly evenly spread over all building types. Most could be attributed to failure in design to make adequate provision for preventing moisture vapour from reaching cold, sensitive parts of the structure. The most serious cases in roof spaces were found over swimming pools; some roofs needed complete replacement after only a few years' service and in others the corrosion of metal supporting structures will be a continuing problem. In some instances, no steps had been taken to avoid interstitial condensation and remedial measures were difficult and expensive.

**Entrapped water** Dampness due to water entrapped during construction can, in some instances, take years to dry.[163] Heavy concrete roof structures, especially where the insulation was in the form of aerated concrete screeds, gave the most trouble.[8] Construction water contributed to this but the main source appeared to be rain or snow falling during the construction period so that even the so-called 'dry' insulating screeds gave some trouble. Blistering of roofing felts,[144] caused by water trapped between successive layers of felt, was also a fairly common cause of complaint.

**Rising damp** Only a few cases of rising damp were reported. Its occurrence in floors was usually in new property where a satisfactory damp-proof membrane [54] had either not been specified or had been badly installed. Failure or staining of floor finishes frequently followed. Most of the walls [27, 77] investigated had a previous history of dampness and proprietary (chemical or 'electro-osmotic') damp-proof courses had been installed, apparently without success. In some instances, the proprietary system had not been properly installed; in others, it had patently failed to stop the rising damp.

## Defects other than dampness (*see* Table 3)

Cracking (structural and superficial) and detachment (usually of finishes or 'veneers') comprised two-thirds of all defects other than dampness.

**Cracking** [75] The few cases of cracking due to foundation movement were attributable to the presence, or recent removal, of trees close to buildings on shrinkable clay. Cracking in floors was nearly all in industrial or office buildings, due either to excessive loadings or to faults in design or execution that impaired the performance of the floors.[47, 104] Much of the cracking in walls, loadbearing or non-loadbearing, and in finishes was caused by differential moisture movement between adjacent parts of the structure. There were more complaints of cracking in private houses than in council houses but

| Building type | Proportion of total sample No | % | Most common defects | Incidence in building type % |
|---|---|---|---|---|
| HOUSING | | | | |
| Council houses | 64 | 13 | Condensation<br>Rain penetration | 59<br>13 |
| Council flats | 55 | 11 | Rain penetration<br>Condensation | 38<br>33 |
| Private houses | 65 | 13 | Rain penetration<br>Cracking<br>Condensation | 33<br>20<br>18 |
| Private flats | 11 | 2 | Rain penetration | 64 |
| NON-HOUSING | | | | |
| Offices; public buildings | 90 | 18 | Floors<br>Roofs<br>Rain penetration<br>Cracking | 28<br>23<br>28<br>19 |
| Factories | 65 | 13 | Cracking (mainly floors)<br>Rain penetration (mainly roofs) | 29<br>29 |
| Schools | 28 | 5 | Roofs<br>Floors (mainly finishes) | 39<br>32 |
| Hospitals | 23 | 5 | Floors (mainly finishes)<br>Roofs | 35<br>26 |
| Swimming pools | 13 | 3 | Detachment of tiles<br>Roof-space condensation | 46<br>46 |
| Universities; colleges | 21 | 4 | No clear pattern | |
| Shops | 18 | 4 | | |
| Churches | 10 | 2 | | |
| Other | 47 | 9 | | |

**Table 1** Sample analysed by type of structure, showing also the most commonly occurring defects

this was probably due to possible effects on the value of the houses.

**Detachment** Detachment of brick slips or rendering from multi-storey framed flats was the third most common complaint about council flats. Shrinkage and creep of the frame, combined often with expansion of the brick infilling, placed unintentional loads on the slips or rendering covering the edges of the floor slabs. Normally, no provision had been made in the design for this differential movement. Similarly, where tiles or mosaics became detached, movement joints had seldom been provided even though they are recommended in Codes of Practice. Tiling adhesion also gave trouble, mainly because a wrong adhesive had been specified or the correct one mishandled. Detachment of floor finishes was commonest with impervious sheet materials; dampness in the substrate affecting the adhesives[54] was the most common cause, but there were some cases of loss of plasticiser by migration into unsuitable flooring adhesives[33] or because of over-aggressive chemical cleaning agents. Detachment of paint films[106] was often traced to the use of wood primers with poor mechanical properties, particularly when damp. Many of the shop-applied primers used in recent years have been inadequate in this respect. Some of the newer non-lead primers compare unfavourably with the older lead-based (toxic) materials, but a forthcoming British Standard for wood primers should help to avoid this.

## Causes of defects (*see* Table 4)

**Faulty design** The largest single type of fault was in making the wrong choice of material or component for a particular situation, eg a wrong adhesive for floor tiles on a heated sub-floor, or the use of cavity fill outside the recommendations of its Agrément Certificate. Necessary cavity trays and flashings were sometimes absent from the design but inadequacies seemed often to stem from poor detailing of the situation where damp-proofing layers had to meet obstructions. Many designers provided only a vertical section through some part of the structure; in practice, difficulties occurred not on the line of the section but at the ends of windows and at returns, and these were seldom, if ever, illustrated adequately.

Other faults included the omission of solar-reflective treatment on flat roofs; poor detailing of special, locally made, wood windows and a tendency to support so-called lightweight partitions inadequately, often on timber floors. Some designs were so complex that they were not likely to be properly executed; these too were classed as faulty. A fault could also be in a bought-in component, such as a window unsuited to the severe exposure for which it was knowingly supplied, or in a sub-contracted service.

**Faulty execution** Water entrapped during construction was the commonest cause of trouble. Water would drip from lightweight insulating screeds

| Type of dampness | | Detailed breakdown | | | | Cause | |
|---|---|---|---|---|---|---|---|
| **Rain penetration** | 136 | through walls | 57 | of masonry | 39 | direct penetration of solid walls | 8 |
| | | | | | | direct penetration of cavity-filled walls | 15 |
| | | | | | | poor dpms, trays, etc | 16 |
| | | | | of concrete panels (through joints) | 10 | | |
| | | | | other | 8 | | |
| | | through roofs | 49 | | | | |
| | | through windows | 17 | | | | |
| | | other | 13 | | | | |
| **Condensation** | 90 | surface | 56 | council housing | 38 | inadequate heating or ventilation | 48 |
| | | | | private housing | 10 | | |
| | | | | other | 8 | | |
| | | interstitial | 34 | housing | 14 | inadequate vapour control in design | 22 |
| | | | | factories | 4 | | |
| | | | | offices | 4 | | |
| | | | | hospitals | 2 | | |
| | | | | other | 10 | | |
| **Entrapped water** | 29 | in roof structure or insulation | | | 19 | | |
| | | in floor structure | | | 4 | | |
| | | other | | | 6 | | |
| **Rising damp** | 23 | in walls | 18 | dpc failure | 12 | | |
| | | in floors | 5 | | | | |
| **Other** | 4 | (There was some overlap between categories) | | | | | |

**Table 2** Analysis of 254 'dampness' defects (=50 per cent of total sample)

for months, sometimes years, after construction. Other faults stemming from this included efflorescence on plastered brickwork and disruption of floorings from water trapped between an impervious flooring and a damp-proof membrane below a thick floor slab.

Poor execution of damp-proof membranes, flashings and cavity trays was also a frequent cause of defects; even when the design was satisfactory, a damp-proof layer might be incomplete or absent. Leaking mastic joints, mostly to windows, were an important cause of failure, usually because of careless application.

Some other examples of poor execution were misplaced thermal insulation, bridging of floating floors, wrong water/cement ratios or mix proportions for concrete, perforation of water barriers, poor preparation of concrete for subsequent renderings, misuse of tiling adhesives, omission of fixings and wall ties, displaced concrete reinforcement, inaccurate assembly of components.

**Faulty materials and components** These were among the less common causes of defects investigated. Hardcore was sometimes highly reactive chemically, and certain concrete blocks, intended specifically for facing work, were so readily permeable to driven rain that normal designs for damp-proof membranes and cavity trays could not always cope with the flow of water in the cavity. Failures of chemical and 'electro-osmotic' damp-proofing systems, and difficulties with paints have already been mentioned.

**Unexpected user requirements** Surface condensation in housing was, as noted earlier, invariably caused by inadequate heating and/or ventilation. Other instances where the expectations of the occupier worked against the design included the use of very aggressive cleaning agents on vinyl floorings and a few cases where the occupiers were perhaps over-sensitive to minor blemishes or cracking in finishes.

**Table 3** Analysis of 256 defects other than dampness (=50 per cent of sample)

| Type of defect | | Location | |
|---|---|---|---|
| Cracking | 93 | due to foundation movement | 8 |
| | | in floors | 28 |
| | | in loadbearing walls | 20 |
| | | in non-loadbearing walls | 10 |
| | | in wall and floor finishes | 14 |
| | | other | 13 |
| Detachment | 75 | tiles and mosaics | 27 |
| | | floor finishes | 16 |
| | | paints and other finishes | 9 |
| | | other | 23 |
| Other | 88 | | |

## Conclusions

The major short-coming in design appeared to be failure to make use of authoritative design guidance. This could be simply failure to appreciate the value of Codes, Standards and Agrément Certificates or it could be due to the sheer volume of guidance available; it might stem from a disdain for the 'standard solution', based on the assumption that the designer can work out everything from first principles. There was often insufficient attention to detail; most of the problems of rain penetration arose from inadequacies in the design of damp-proof membranes and cavity trays. The fact that so many buildings leak because of patent design faults should not be accepted with equanimity and yet 'the masterpiece which leaks' has been with us for many years. Greater use of standard details could bring an improvement; non-standard details must be thought out in three-dimensional form and illustrated clearly. It should not be left to the man on the site to discover the difficulties, sometimes impossibility, of executing the intended design.

In the field of execution, the pattern was more complex. More individuals are involved in the construction of a building than in its design and there are thus more opportunities for individual failings to emerge. A higher standard of supervision is necessary if the more glaring instances of poor workmanship and the omission of important details are to be avoided. Something better than the present system of spot checks may be necessary in critical areas of the construction, such as the installation of cavity trays in multi-storey construction, of wall ties in brick cladding, and the preparation of backgrounds to receive rendering and tiling. It is most important, throughout the construction period, to give better protection against the worst effects of wet weather and freezing conditions to unfixed materials and components, as well as to structures. All building is subject to some bad weather but relatively few buildings suffer seriously because of it. It seems that even quite simple protective measures during the worst conditions bring considerable benefits.

Faulty materials, etc and unexpected user requirements together accounted for less than a quarter of the defects analysed. It is unlikely that much can be done to counter the effects of changing user requirements but many of the problems with materials and the like could be avoided if designers were more critical in their selection and more precise in specification. They should refuse, much more often, to accept materials, components or systems which do not offer worth while guarantees of performance measured against accepted criteria such as British Standards. In the end, poor products will only survive if designers continue to specify them.

| Cause of defect | | Most common faults in category | |
|---|---|---|---|
| Faulty design | 295 | Choice of material or component | 49 |
| | | Inadequate provision for movement | 38 |
| | | DPMs; flashings; cavity trays, etc | 29 |
| | | Inadequate control of water vapour | 23 |
| Faulty execution | 176 | Entrapment of water | 41 |
| | | Leaking mastic joints | 17 |
| | | Poor execution, omission of DPMs, flashings, cavity trays, etc | 21 |
| Faulty materials, components or proprietary systems | 63 | Non-conventional dpc system | 12 |
| | | Paints | 7 |
| Unexpected user requirements | 58 | Condensation due to inadequate ventilation | 48 |
| Other | 8 | | |

(There was some overlap between categories)

**Table 4** Causes of defects analysed

**References (BRE DIGEST numbers)**


8 Built-up felt roofs
27 Rising damp in walls
33 Sheet and tile flooring made from thermoplastic binders
47 Granolithic concrete, concrete tiles and terrazzo flooring
54 Damp-proofing solid floors
75 Cracking in buildings
77 Damp-proof courses
104 Floor screeds
106 Painting woodwork
108 Standardised U-values
110 Condensation
140 Double glazing and double windows
144 Asphalt and built-up felt roofings: durability
163 Drying out buildings



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